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Renewable Energy Conversion and Storage - Overview

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Publication date:
2012

Citation (APA):
Mogensen, M. B. (Author). (2012). Renewable Energy Conversion and Storage - Overview. Sound/Visual production (digital)

Renewable Energy Conversion and Storage - Overview

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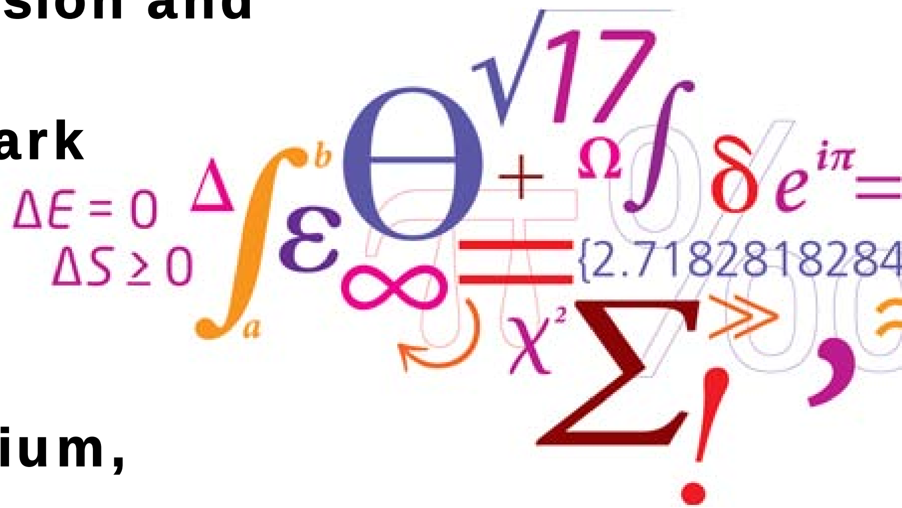


2012 Energy Storage Symposium,

Outline

- Introduction
- The availability and possibility of renewable energy
- Storage capacity and methods
- Consumption and storage types
- Characterization and evaluation of energy storage systems
- Storage for the electrical grid
  - Some technology status
- Storage for transportation sector
  - Why synthetic hydrocarbons
  - Visions
  - Electrolysers
  - Some status
- Intelligent energy systems + combining technologies
- Concluding remarks

Introduction

- **Wish to increase the production of sustainable and CO_2 neutral energy - "green house" effect – not enough inexpensive oil**

- **Denmark aims to become independent of fossil fuel by 2050.**

  Energy strategy 2050 - from coal, oil and gas to green energy, The Danish Government, February 2011, http://www.ens.dk/Documents/Netboghandel%20-%20publikationer/2011/Energy_Strategy_2050.pdf

- **Natural to look for photosynthesis products (biomass), but not enough biomass**

  H. Wenzel, “Breaking the biomass bottleneck of the fossil free society”, Version 1, September 22nd, 2010, CONCITO, http://www.concito.info/en/udgivelser.php

Enough renewable energy?

- **Yes, fortunately, enough is <u>potentially</u> available.**

- **Annual global influx from sun is ca. 3 - $4 \cdot 10^{24}$ J - marketed energy consumption is ca. $5 \cdot 10^{20}$ J;**

  1)A. Evans et al., in: Proc. Photovoltaics 2010, H. Tanaka, K. Yamashita, Eds., p. 109.

  2) Earth's energy budget, Wikipedia, http://en.wikipedia.org/wiki/Earth's_energy_budget.

  3) International Energy Outlook 2010, DOE/EIA-0484(2010), U.S. Energy Information Administration, http://www.eia.gov/oiaf/ieo/index.html

- **Earth's surface receives ca. 6 - 8,000 times more energy than we need. In deserts, intensity is higher than average at the same latitude – dry air**

Is it doable?

- If 0.2 % of the earth's area (ca. 1 mill. km^2 or 15 % of Australia) and if collection efficiency = 10 %, we get enough energy.

- Besides solar we also have geothermal and nuclear (fusion and fission) potential energy sources.

- CO_2 free nuclear - more efficient if affordable storage technology is available.

- Important part of the solar energy is actually converted to biomass, hydro and wind energy – easier to harvest.

- Thus, the conclusion is: yes, technically, it is doable.

Energy storage capacity

- Now (2008) world-wide electric power production: 3400 GW and equiv. storage is 90 GW or ca. 2.5 % – mainly PHS

- Yearly Electric energy production: 3.4 10^{12} W x 8760 h x 3600 s = $1 \cdot 10^{20}$ J compared to marketed energy consumption ca. $5 \cdot 10^{20}$ J, i.e ca. <u>20 % of total</u>

- Today most energy (fossil fuel) is temporarily stored as coal, oil or gas, i.e. we have storage capacity for most of our energy

- Can we use some of this capacity for renewable energy storage?

Renewable energy production methods

- **Solar (Concentrated – CSP; Photo-voltaic – PV; Artificial photosynthesis, APS)**
- **Wind**
- **Hydro**
- **Tides and waves**
- **Geothermal**
- **Biomass**
- **(Nuclear)**

They will all need or at least benefit from affordable storage systems

Transportation of the energy is an issue in all cases

Energy consumption types

- The electric grid
- The natural gas grid
- Remote electric
- Energy for the transportation (Airplanes, Trains, Ships, busses, passenger cars, Machines in industry and farming.
- Portable electric

Energy Storage Types

- Pumped hydro storage, PHS
- Compressed air energy storage, CAES
- Flywheel

- Superconducting magnetic energy storage, SMES

- Electrolysis / fuel cells, hydrogen and synthetic hydrocarbon fuels, SHC
- Flow battery
- Battery
- Super capacitor

- Thermal energy storage

Characteristics of energy storage techniques

Energy storage techniques can be classified according to many criteria, e.g.:

- **The type of application: permanent or portable.**
- **Storage duration: short or long term.**
- **Storage weight and volume**
- **Type of electricity production: maximum power needed.**

How to evaluate renewable energy systems?

Three resent workshops on energy conversion and storage:

1. ***International workshop on integration of wind energy*, Aarhus, Denmark October 2011: Electrolysis, batteries or any other kind of chemistry was hardly mentioned. Only HVDC pumped hydro storage is necessary. The transport sector uses batteries.**
2. ***"Green" methanol workshop*, Potsdam, Berlin, November 2011. Almost only CO_2 neutral methanol and hydrocarbon presentations were given: Hydro storage was ruled out as sufficient possibility. Methanol and maybe other HCs are necessary.**
3. ***Hydrogen for transportation* at DTU Risø Campus, December 2011: Hydrogen the only possible solution. Claimed: "The Germans do not need synthetic hydrocarbons".**

Complexity of evaluating storage technologies

H.Ibrahim, A.Ilinca, J.Perron, “Energy storage systems-Characteristics and comparisons”, *Renewable and Sustainable Energy Reviews*, 12 (2008) 1221–1250; i.e. 30 pages.

Good paper but an electric grid view mainly! Good as <u>example</u>.

1. Introduction
2. Storage and renewable energy
3. Technical and economical advantages of energy storage
3.1. Energy transfer
3.2. Network savings
3.3. The kinetic advantage
4. Electricity storage systems
4.1. Pumped hydro storage (PHS)
4.2. Thermal energy storage (TES)
4.3. Compressed air energy storage (CAES)
4.4. Small-scale compressed air energy storage (SSCAES)

Continued

4.5. Energy storage coupled with natural gas storage (NGS)
4.6. Energy storage using flow batteries (FBES)
4.7. Fuel cells—Hydrogen energy storage (FC–HES)
4.8. Chemical storage
4.9. Flywheel energy storage (FES)
4.10. Superconducting magnetic energy storage (SMES)
4.11. Energy storage in supercapacitors
5. Characteristics of energy storage techniques
5.1. Storage capacity
5.2. Available power
5.3. Depth of discharge or power transmission rate
5.4. Discharge time
5.5. Efficiency
5.6. Durability (cycling capacity)
5.7. Autonomy

Continued

5.8. Costs

5.9. Feasibility and adaptation to the generating source

5.10. Self-discharge

5.11. Mass and volume densities of energy

5.12. Monitoring and control equipment

5.13. Operational constraints

5.14. Reliability

5.15. Environmental aspect

5.16. Other characteristics

6. Comparison of the different storage techniques

6.1. Power comparison as a function of field of application

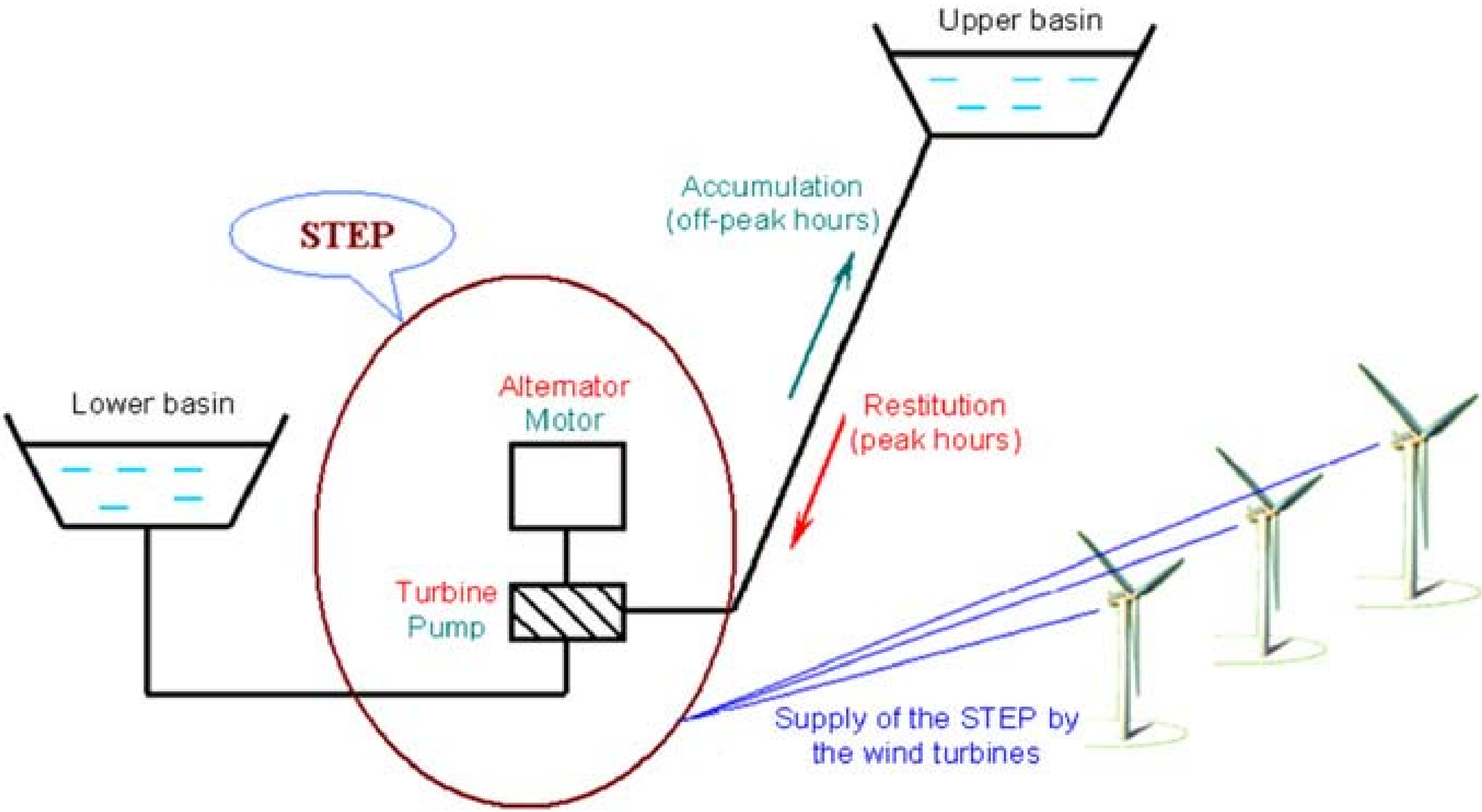
6.2. Comparison of the energy efficiency (per cycle) of the storage systems

6.3. Comparison of the investment cost

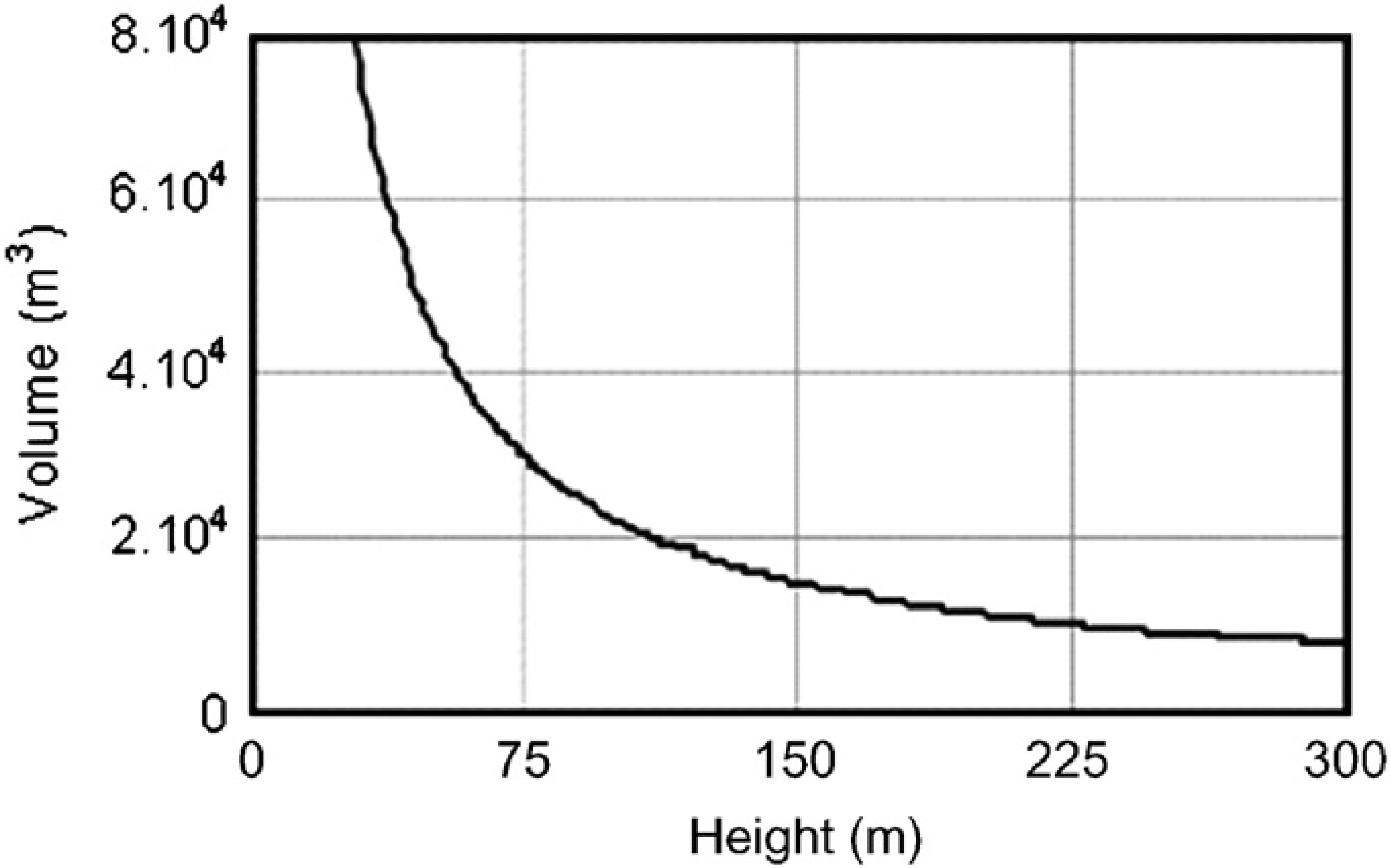
6.4. Comparison of the investment cost per charge–discharge cycle

6.5. Comparison based on mass or volume density

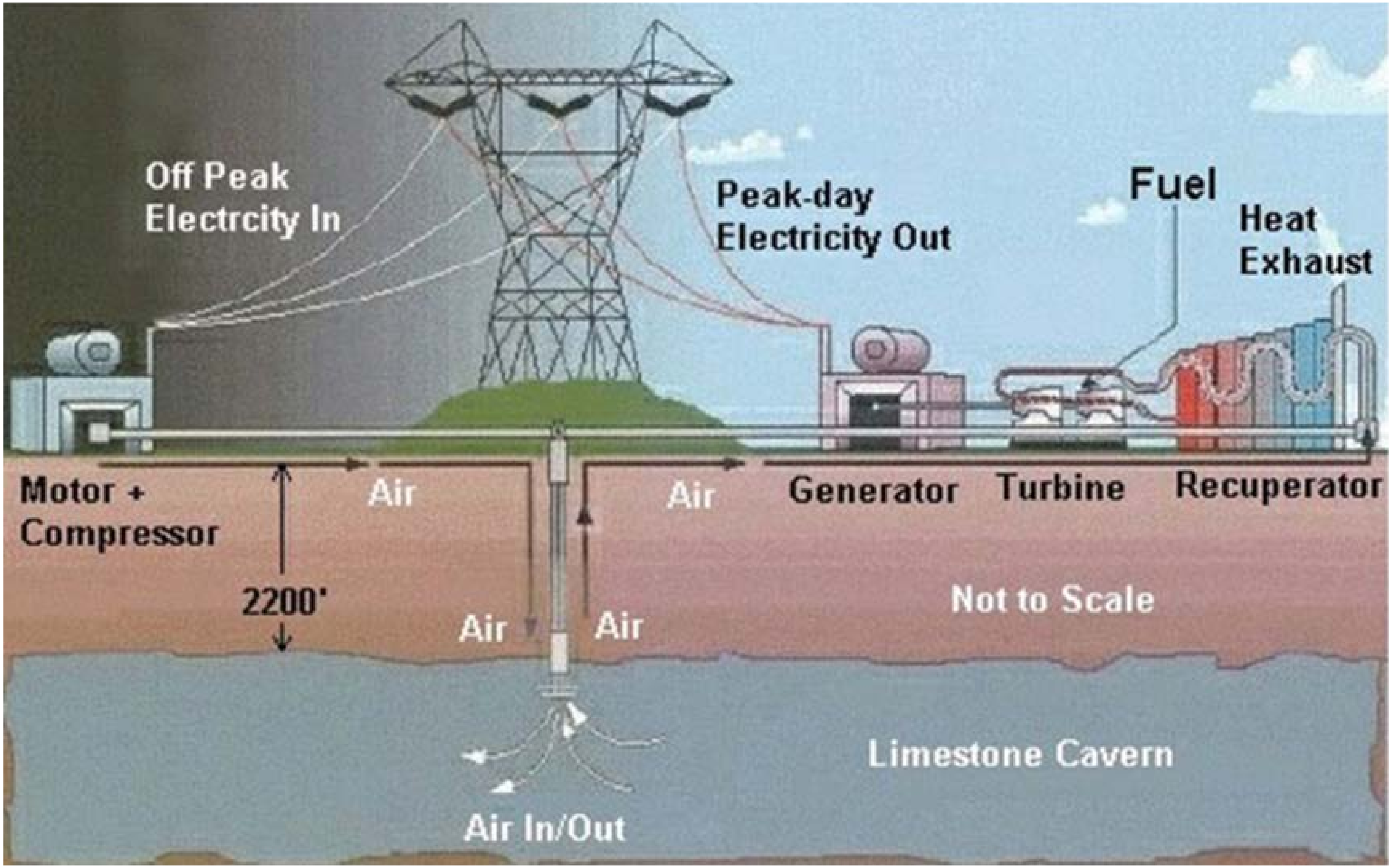
Pumped hydro storage with energy supplied by wind turbines



Water volume needed at a given height to store 6MWh



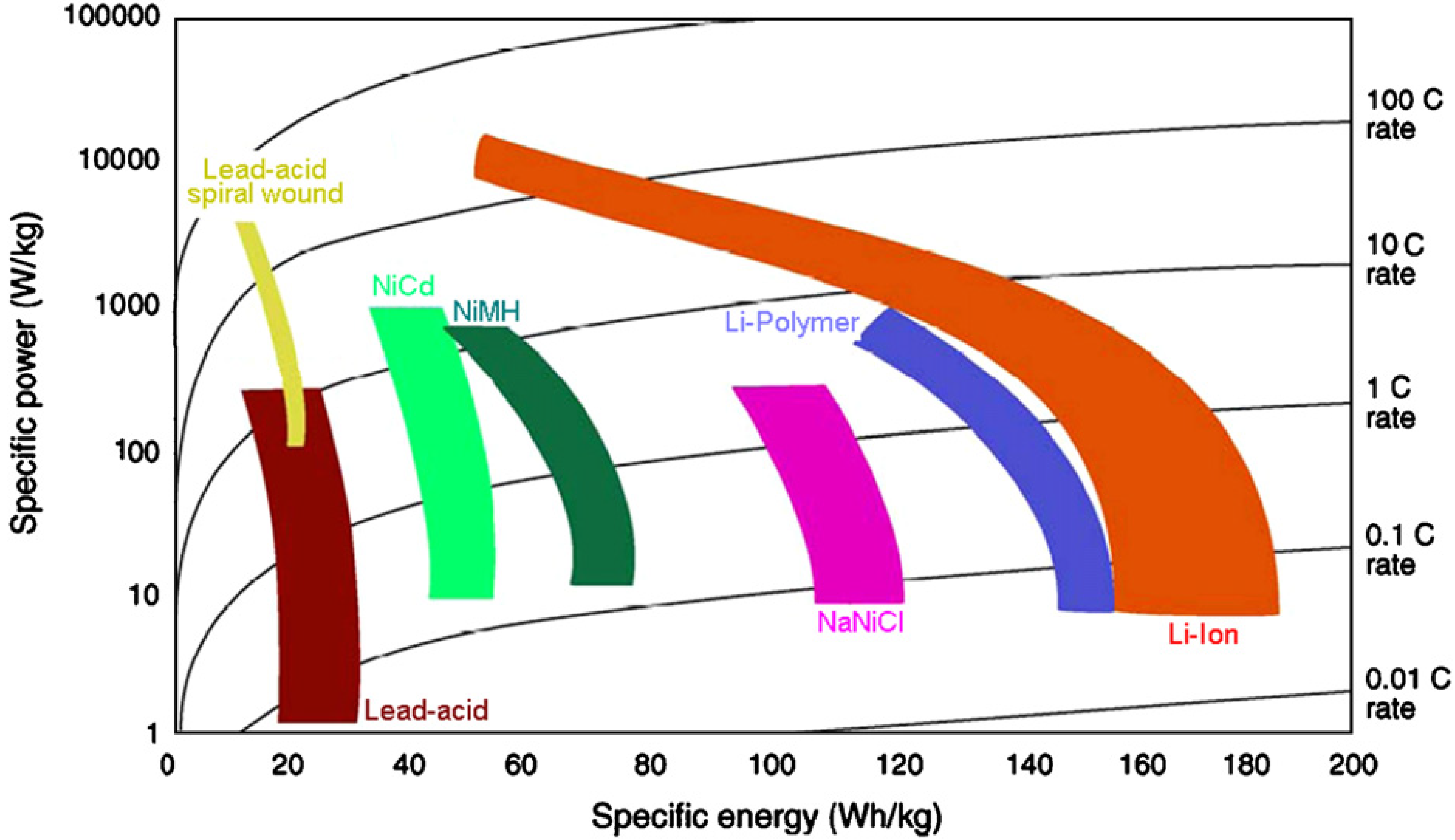
Compressed-air energy storage



Some status

- PHS is available and used many places already. French nuclear power in Swiss alps – Danish wind in Norway.
- Often not any pumping – HP production just stopped.
- CAES also tried in large scale
- Observed efficiencies:
- PHS: 65 – 80 %
- CAES: 70 %
- SSCAES (small scale): 50 %

Ragone diagram for electrochemical accumulators



Another "evaluation" example

Device Price List	
Technology	**Cost ($/kWh)**
Electrostatic capacitor	2,500,000
Electrolytic capacitor	1,000,000
Electochemical capacitor ("super" or "ultracapacitor")	20,000
Li-ion battery	1000
Lead acid battery	150

From: J.R. Miller, *Science*, **335**, 1312 (2012)

All have their markets!

Why synthetic hydrocarbons (SHC)? The energy density argument

Type	MJ/l	MJ/kg	Boiling point °C
SHC - Gasoline,	33	47	40 - 200
SHC - Dimethyl ether - DME	22	30	- 25
Liquid hydrogen	(10)	(141)	-253
PHS, Water at 100 m elevation	10^{-3}	10^{-3}	
Lead acid batteries	0.4	0.15	
Li-ion batteries	1	0.5	

Why SHC?
The power density argument

- Gasoline filling rate of 20 L/min equivalents 11 MW of power and means it takes 2½ min to get 50 l = 1650 MJ on board

- For comparison: Li-batteries usually requires 8 h to get recharged. For a 300 kg battery package (0.5 MJ/kg) this means a power of ca. 3.5 kW i.e. it takes 8 h to get 150 MJ on board.

- The ratio between their driving ranges is only ca. 5, because the battery-electric-engine has an efficiency of ca. 70 % - the gasoline engine has ca. 25 %.

Visions for synfuels from electrolysis of H_2O and CO_2

1. Big off-shore wind turbine parks, coupled to a large SOEC system producing methane (synthetic natural gas, SNG), which is fed into the existing natural gas net-work (in Denmark).

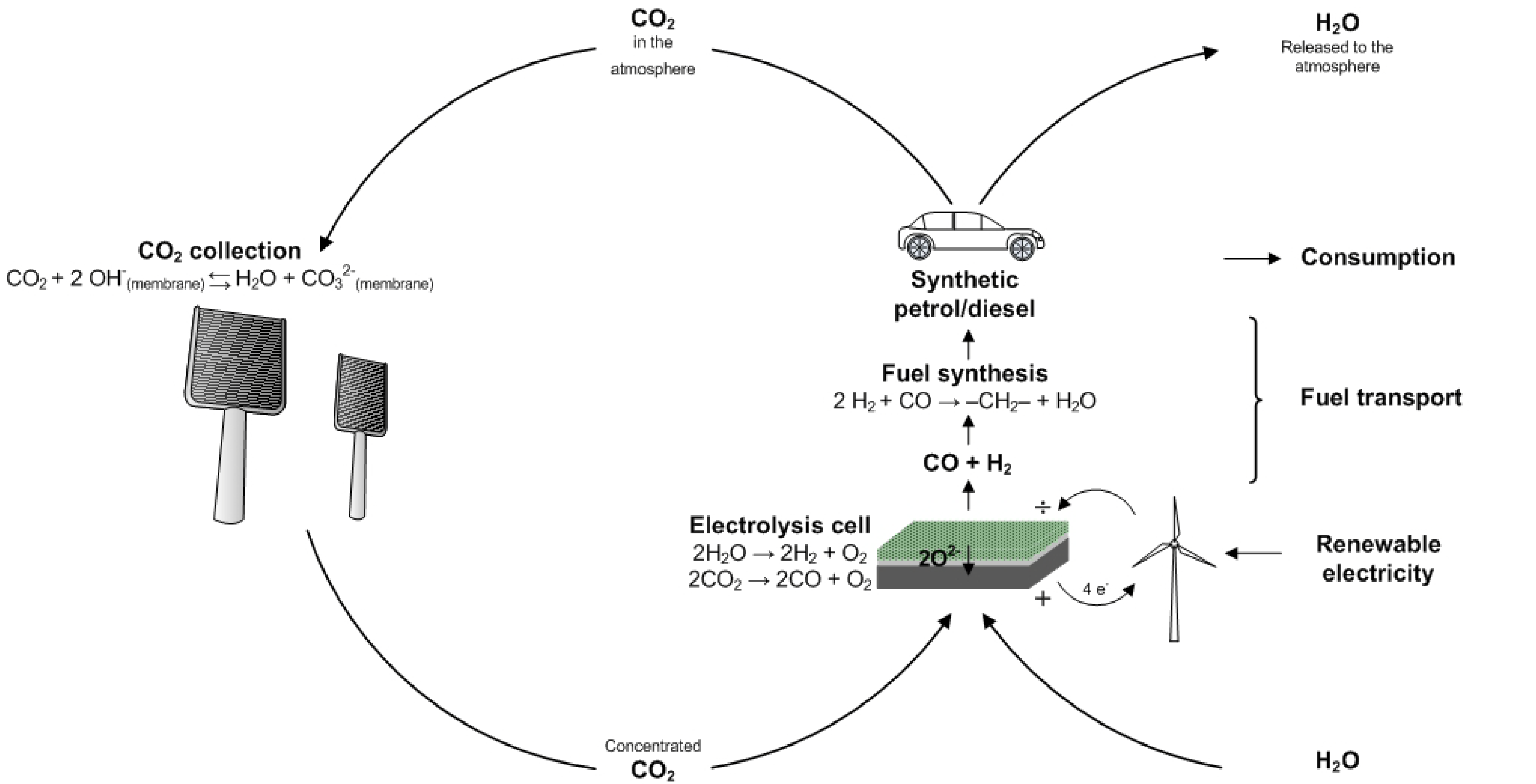
2. Large SOEC based systems producing DME, synthetic gasoline and diesel in Island, Canada, Greenland, Argentina, Australia … driven by geothermal energy, hydropower, solar and wind.

3. The target market should be replacement of natural gas and liquid fuels for transportation

4. All the infrastructure exists!!

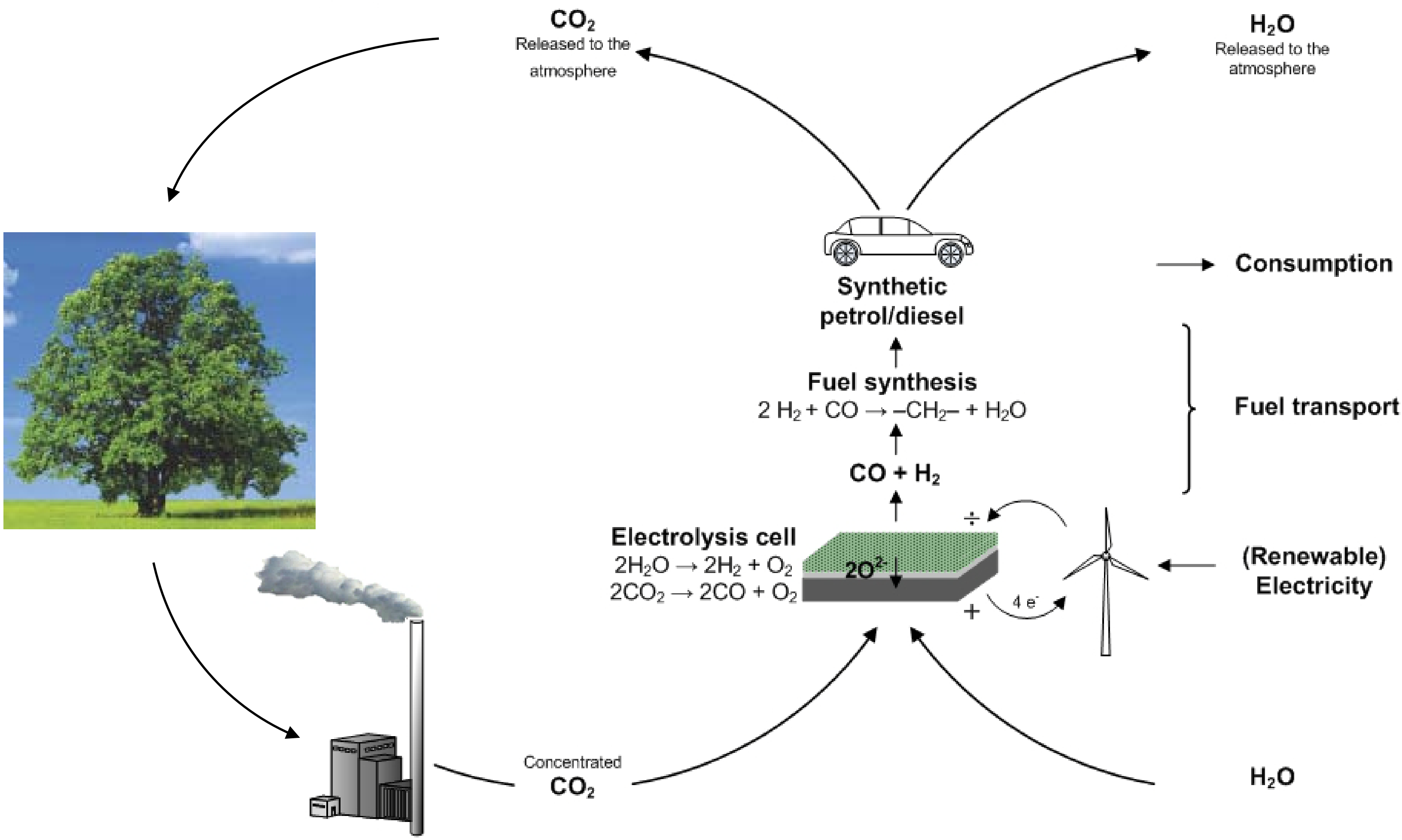
Vision, co-electrolysis for transport fuels

Long term realisation - CO_2 capture from the atmosphere



Vision, Biomass CO_2 recycling

Short term realisation - CO_2 capture from industrial sources



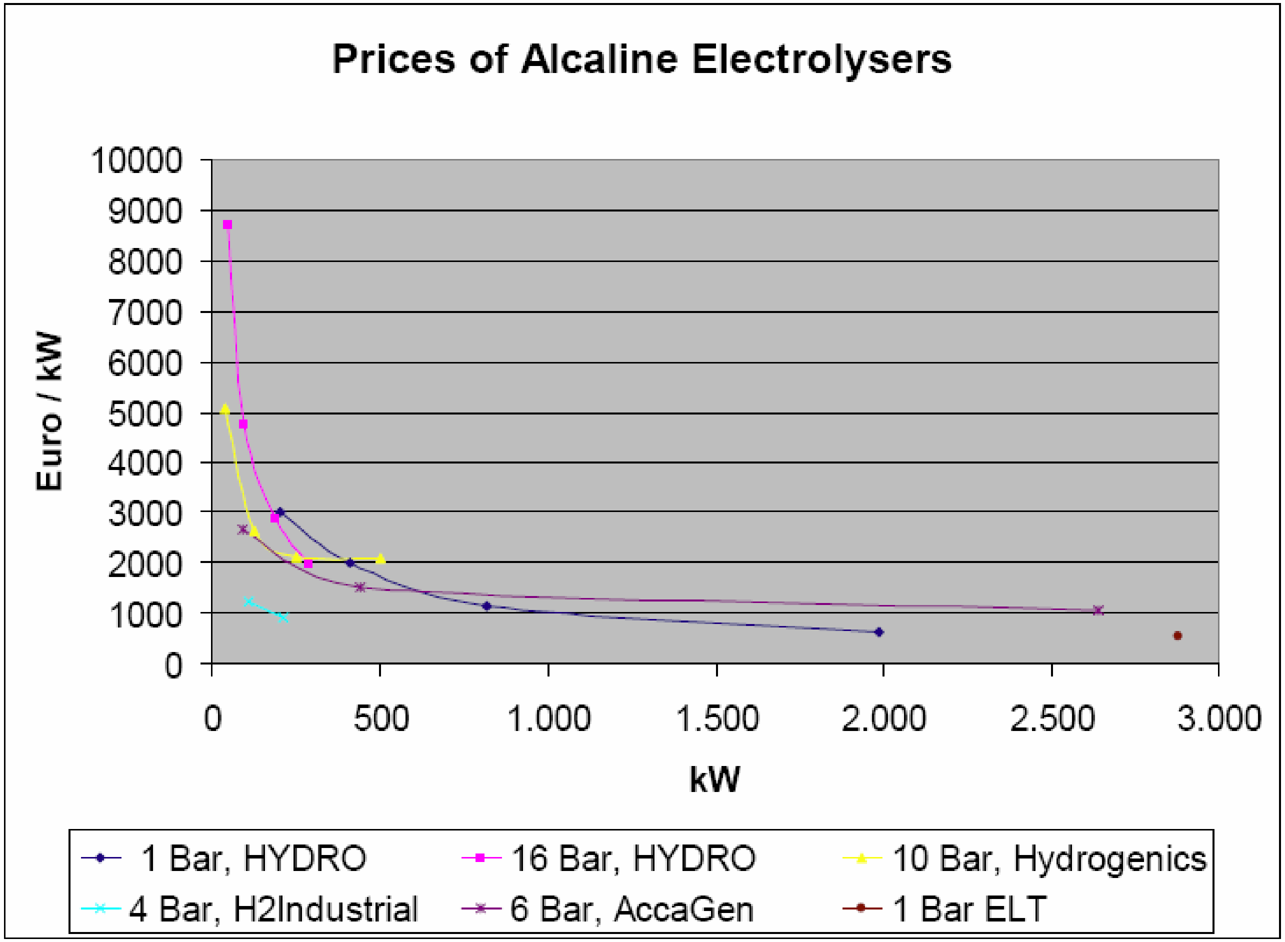
The classical alkaline electrolyser

- If synfuel production using electrolysis in very near future then only option would be alkaline electrolyser - commercialized during the first half of the 20th century.

- Problem: hydrogen gets expensive, low production rate or low efficiency.

- Further, the hydrogen have to react with CO_2 (not CO) to make synfuel – H_2O product results

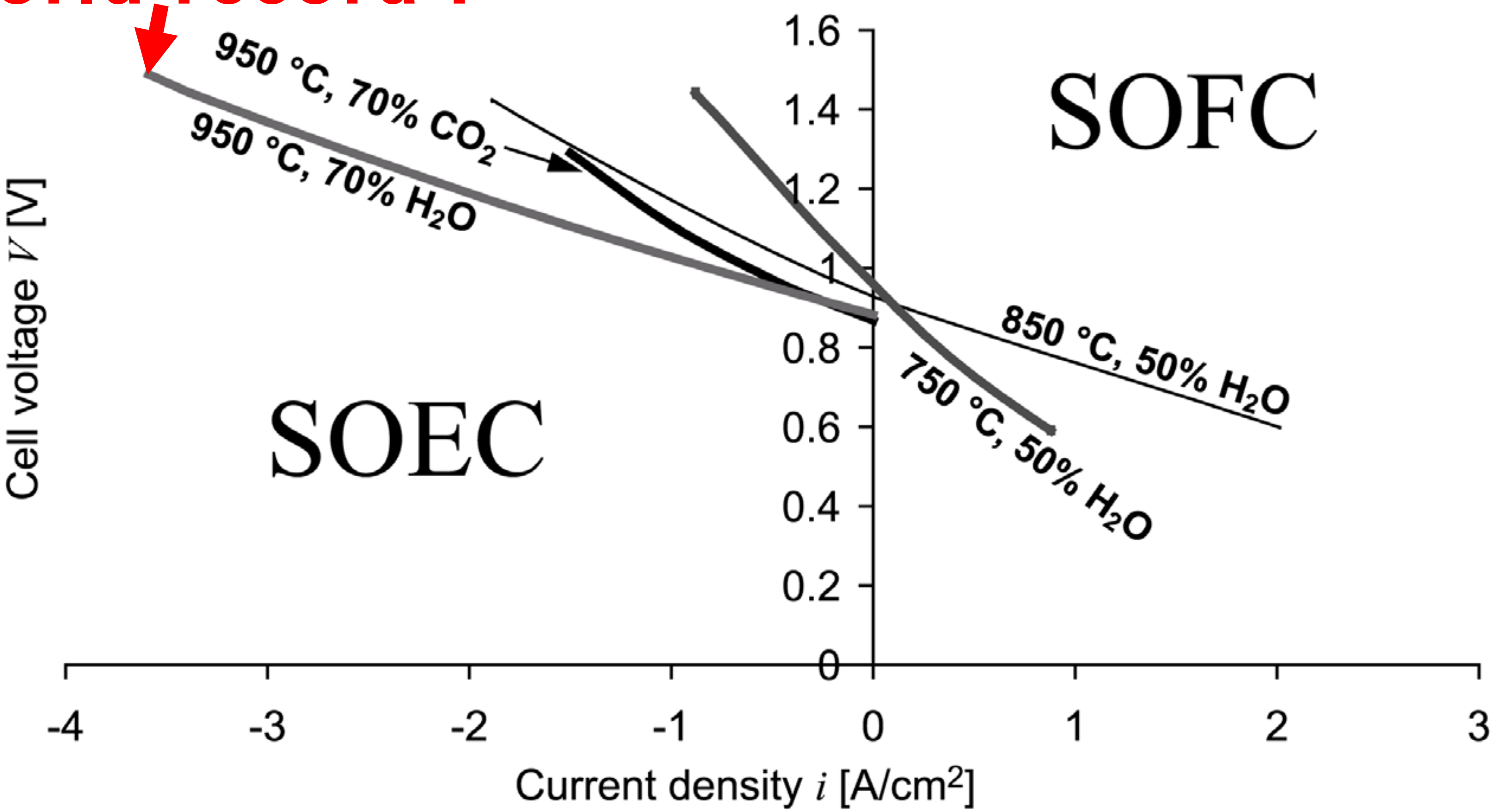
Prices of different electrolyzers as a function of production rate capability / power



Ref.: J.O. Jensen, V. Bandur, N.J. Bjerrum, S.H. Jensen, S. Ebbesen, M. Mogensen, N. Tophøj, L.Yde, "Pre-investigation of water electrolysis“, PSO-F&U 2006-1-6287", project 6287 PSO, 2006, p. 134. http://130.226.56.153/rispubl/NEI/NEI-DK-5057.pdf

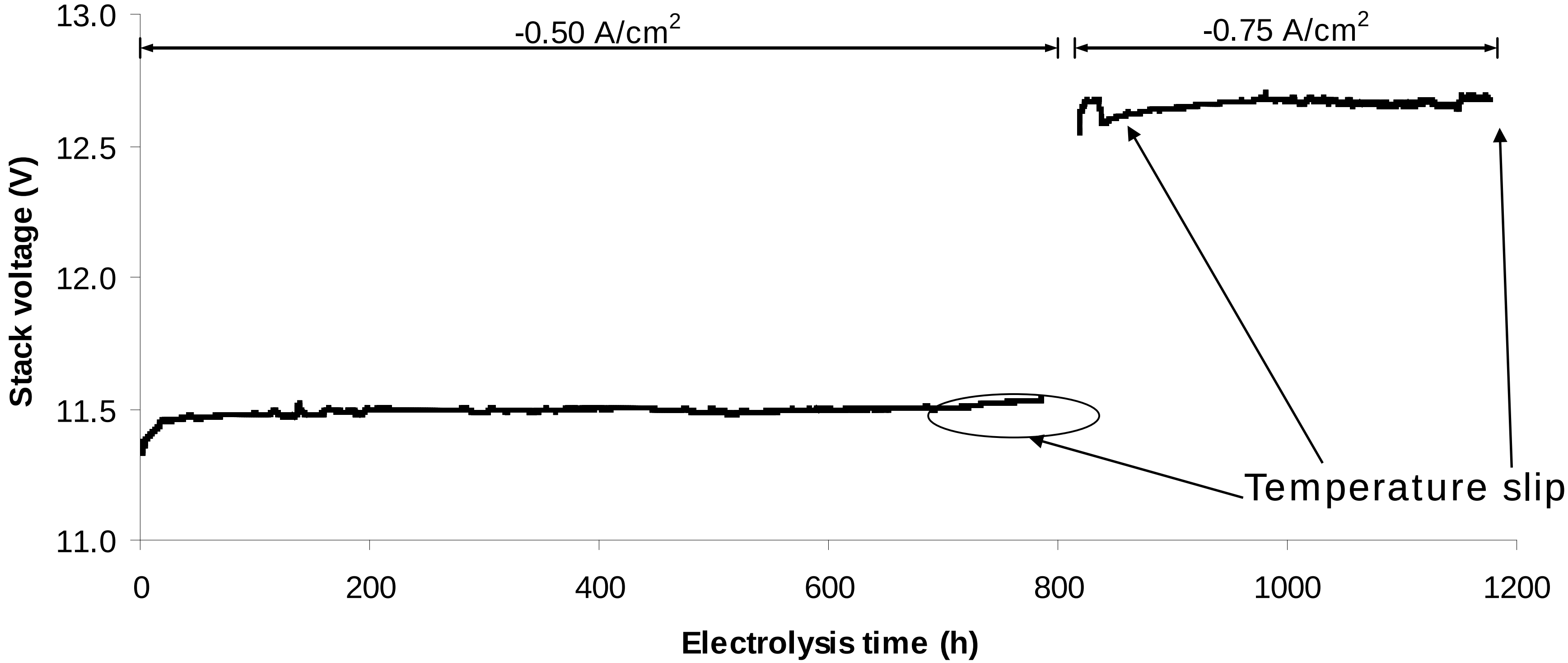
Solid Oxide Cell (SOC) performance

World record !



i - V curves for a Ni-YSZ-supported Ni / YSZ / LSM SOC: electrolyzer (negative cd) and fuel cell (positive cd) at different temperatures and steam or CO_2 partial pressures - balance is H_2 or CO.

1 kW - 10-cell Topsoe stack – 12×12 cm²



850 °C, -0.50 A/cm² or -0.75 A/cm², 45 % CO² / 45 % H_2O / 10 % H_2

S. Ebbesen et al.

Danish SOC consortium

- Risø DTU, Haldor Topsoe A/S and Topsoe Fuel Cell A/S have close cooperation around solid oxide cell technology.

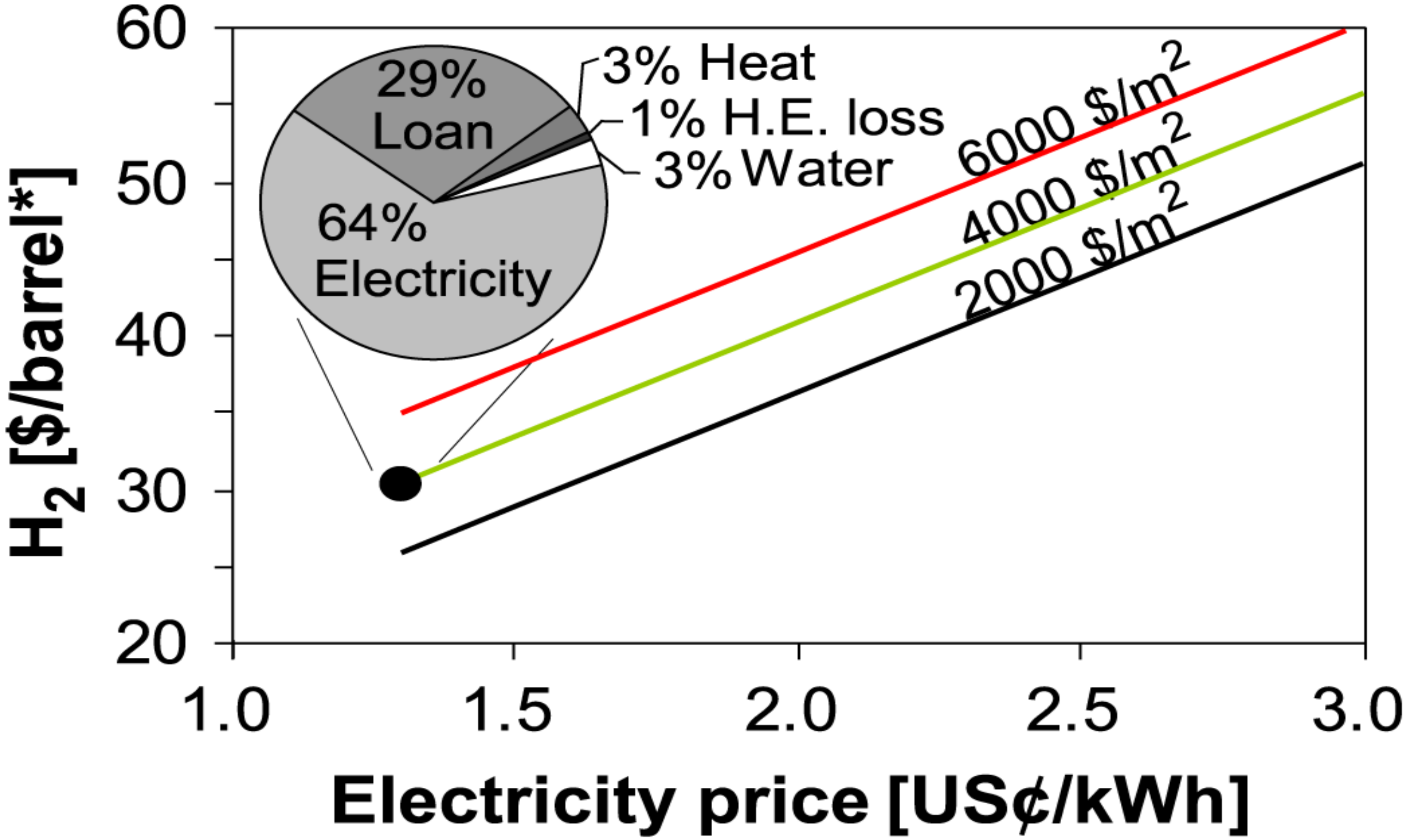
- Topsoe Fuel Cell has a pilot production line for SOC. Haldor Topsøe has a industrial catalyst production and extensive know-how on fuel production from syngas.

New SOFC production facility Topsoe Fuel Cell A/S

- Inauguration: April 2009
- Capacity ≈ 5 MW/yr
- Investment: >13 mio. EUR

Advanced technology – industrial relevance – low production cost

H_2 production by SOEC – economy estimation

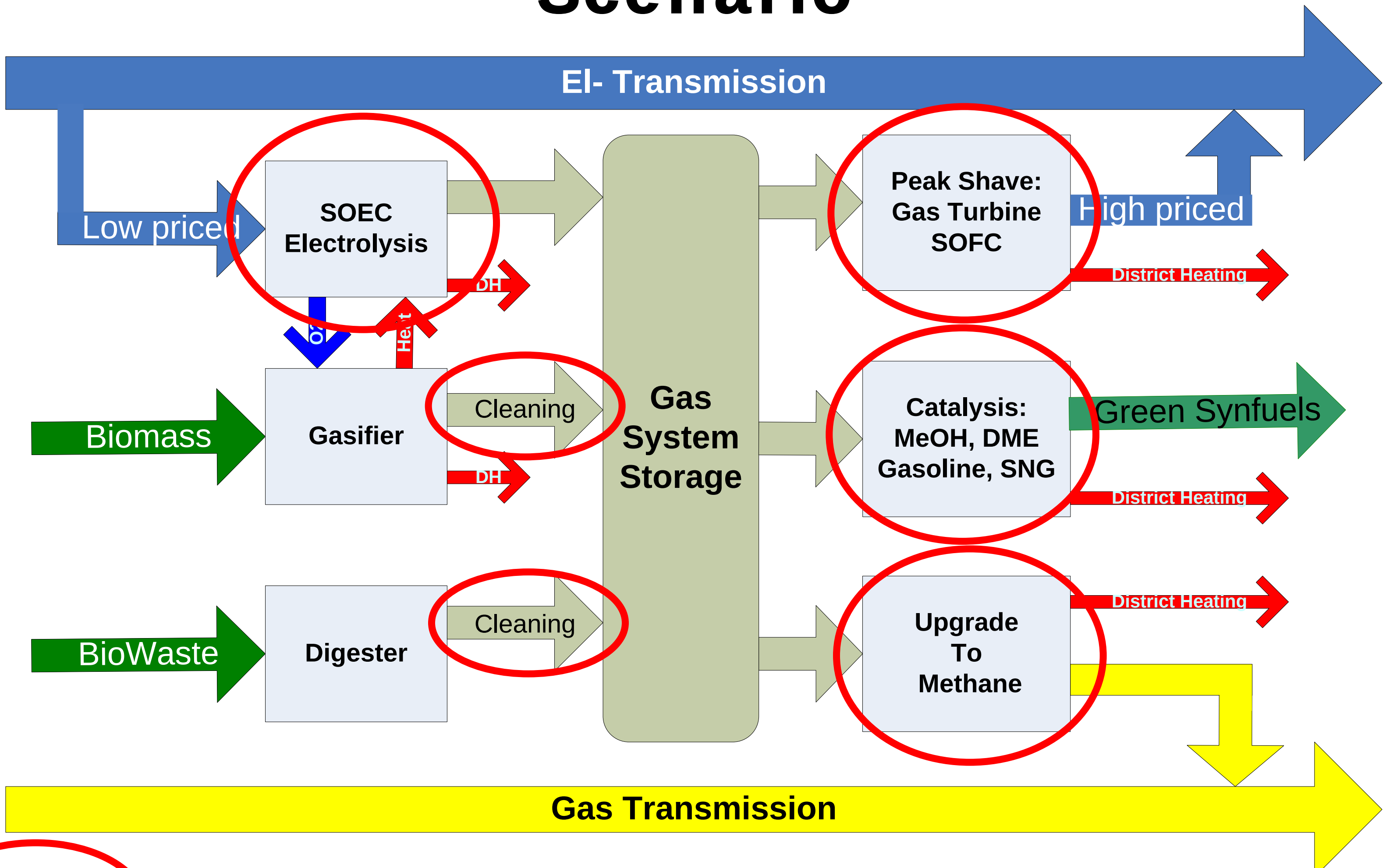


* Conversion of H_2 to equivalent crude oil price is on a pure energy content (J/kg) basis

Intelligent grid and combinations

- Differentiation of price / kWh – use the energy when available
- Send the electricity to the region needed
- Make the local most rational choice of storage type – advantageous to have several options – e.g. super capacitors - seconds of storage, PHS for days, SHC for months and transportation purposes
- Renewable energy “refineries”

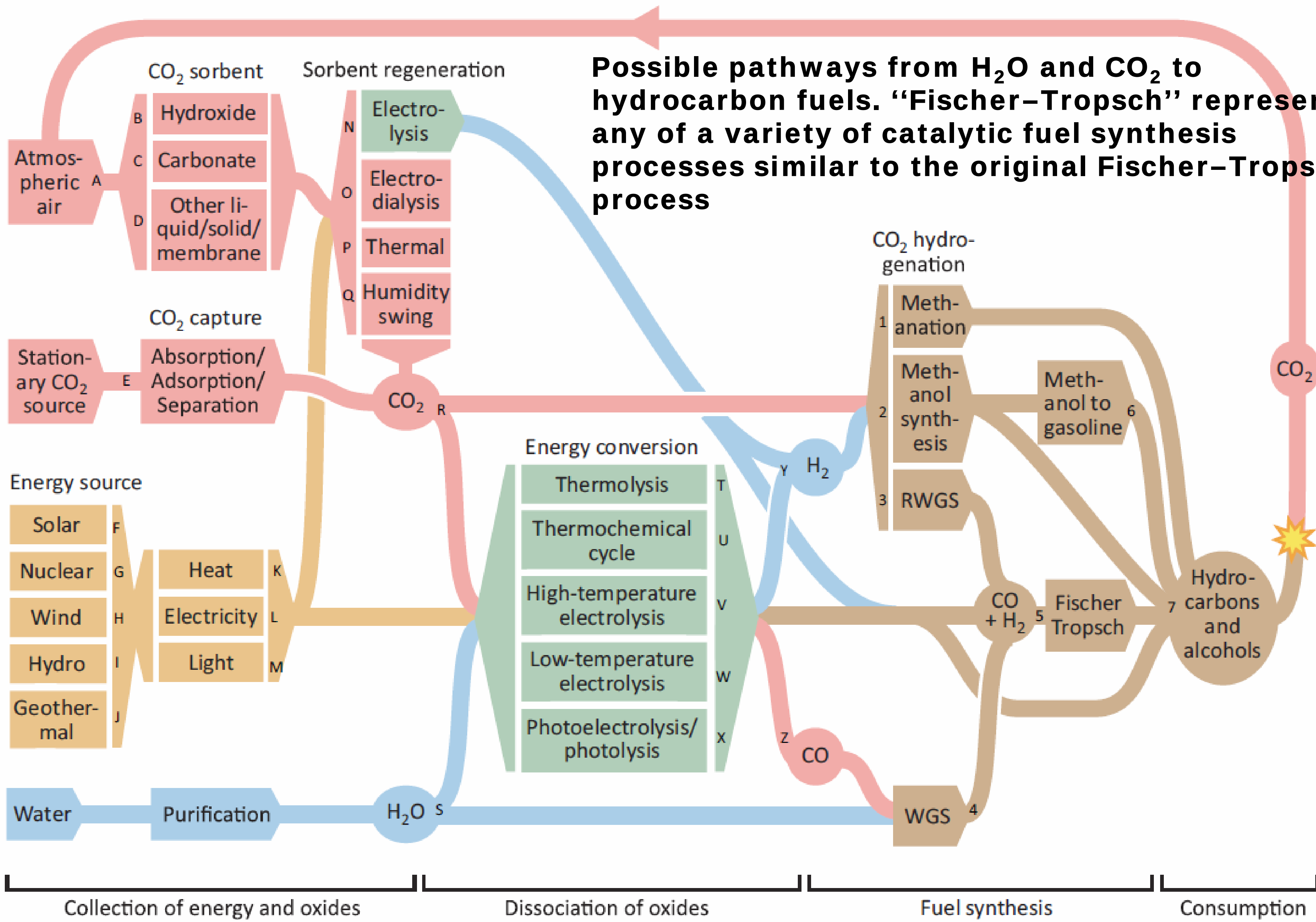
Energinet.dk's vision for fossil fuel free Denmark in 2050 – The Wind Scenario



= Topsøe Technology – Topsøe is a medium sized Danish company

Routes to synthetic fuels

C. Graves et al. / Renewable and Sustainable Energy Reviews 15 (2011) 1–23



Possible pathways from H_2O and CO_2 to hydrocarbon fuels. ''Fischer–Tropsch'' represents any of a variety of catalytic fuel synthesis processes similar to the original Fischer–Tropsch process

Concluding remarks

The following is meant as contributions to the discussion about what is really important and necessary to realize in our further struggle towards affordable, renewable energy.

All known types of energy storage may be needed in the future.

There is fast progress in R&D – the most recent results from the labs has not been included in this presentation, e.g. superconducting cables and SMES with new superconductors

Efficiency versus costs

If an energy technology is sustainable (CO_2 – neutral), constantly available and environmental friendly, then the energy efficiency is <u>not</u> important in itself.

The energy price for the consumer is the only important factor!

SOC electrolysis – fuel cell cycle-efficiency: maybe only 40 %

Efficiency of conversion of fossil fuel in a car: ca. 25 %

Efficiency of production of bio-ethanol??

Competitive to fossil fuel?

- Renewable electricity (wind, solar) + SOC will not be competitive to fossil derived fuels within the foreseeable future.

- Political intervention is absolutely necessary - the free market forces will not save the climate. A suitable high tax on CO_2 is one way.

- The free market will favor cheap coal and natural gas within the foreseeable future.

- Liquid synfuels and SNG can affordably be fabricated from syngas derived from coal. This was previously practiced in large scale in Germany during 2. world war and in South Africa during the blockade period.

So, is 100% renewable energy economically doable?

This depends on a number of issues, because are the majority of the population of the Earth willing to pay for this in order to save the climate?

- Depends on consequences of the evolution of our climate
- Depends on opinion makers (journalists, politicians etc,)

My personal view: We can make it affordable.

Acknowledgements

I acknowledge support from our sponsors

- Danish Energy Authority
- Energinet.dk
- EU
- Topsoe Fuel Cell A/S
- Danish Programme Committee for Energy and Environment
- Danish Programme Committee for Nano Science and Technology, Biotechnology and IT
- The work of <u>many</u> colleagues over the years

Thank you for your attention!